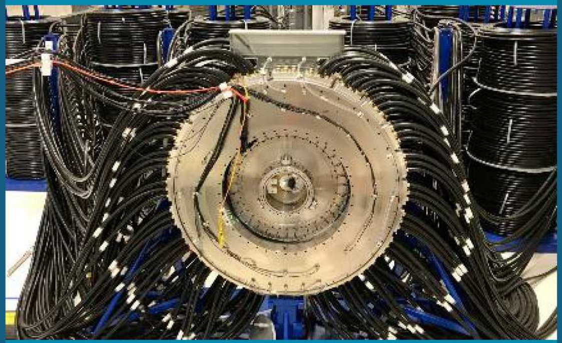
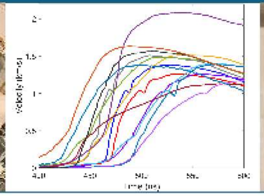
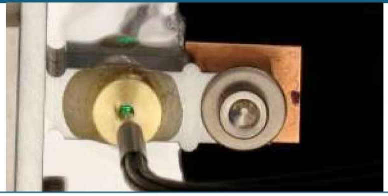
SAND2020-7980PE

Thor: a small pulser available to support ZFSP materials research







Jean-Paul Davis

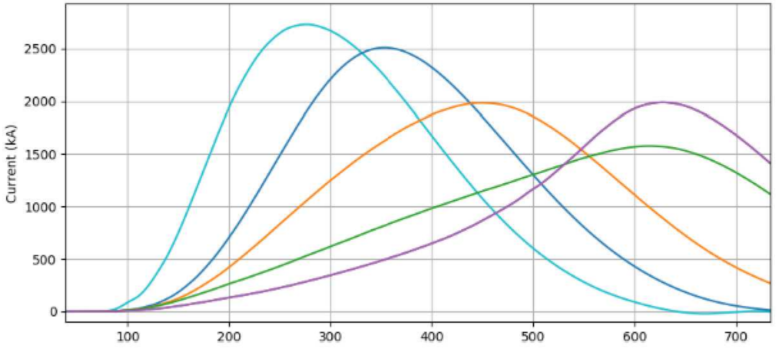
Z Fundamental Science Program 2020 Workshop

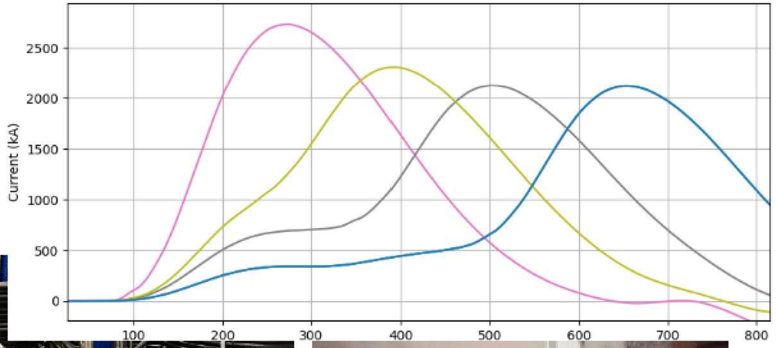
Held online August 3-4, 2020

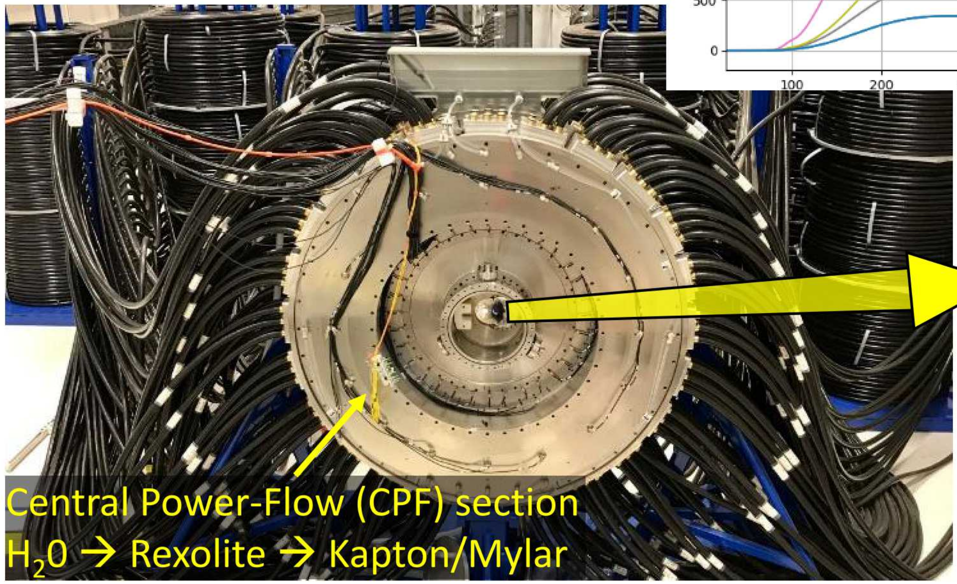
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

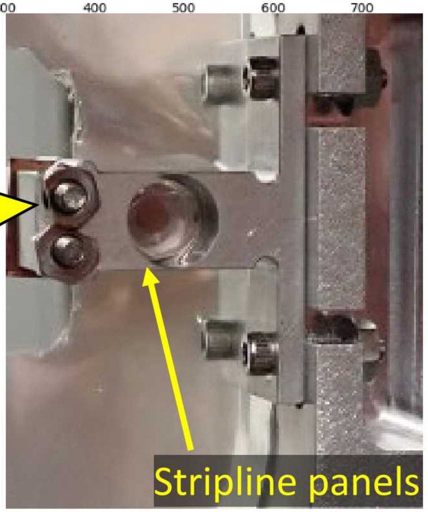
Thor is a ~2-MA pulsed-power machine at Sandia capable of a large range of pulse shapes for ramp loading of materials

- 64 "bricks" (2 capacitors + 1 switch) arranged in 8 towers
- Machine stores 51 kJ electrical energy when charged to 90 kV
- Switching all bricks synchronously delivers ~2.5 MA with ~150-ns rise time
- Independently trigger groups of 4 or 8 bricks, timing spread up to 500 ns
- Peak stress in Al/Cu electrodes of 10-40 GPa at strain rates of $5\times10^5 - 10^7$/s
- Stripline targets allow two identically-loaded samples (or drive + sample)
- Presently operate at 2 shots/week, but 4 shots/day possible with full support

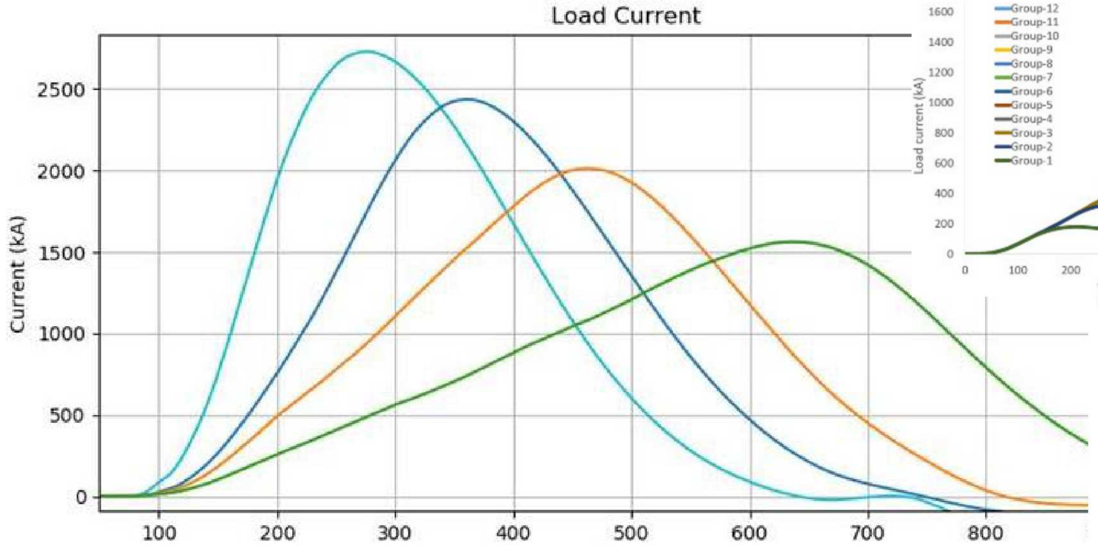


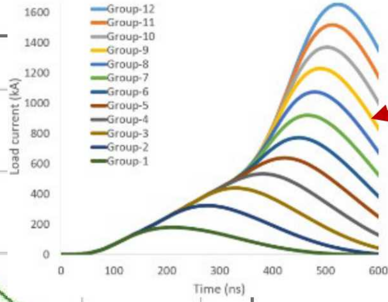




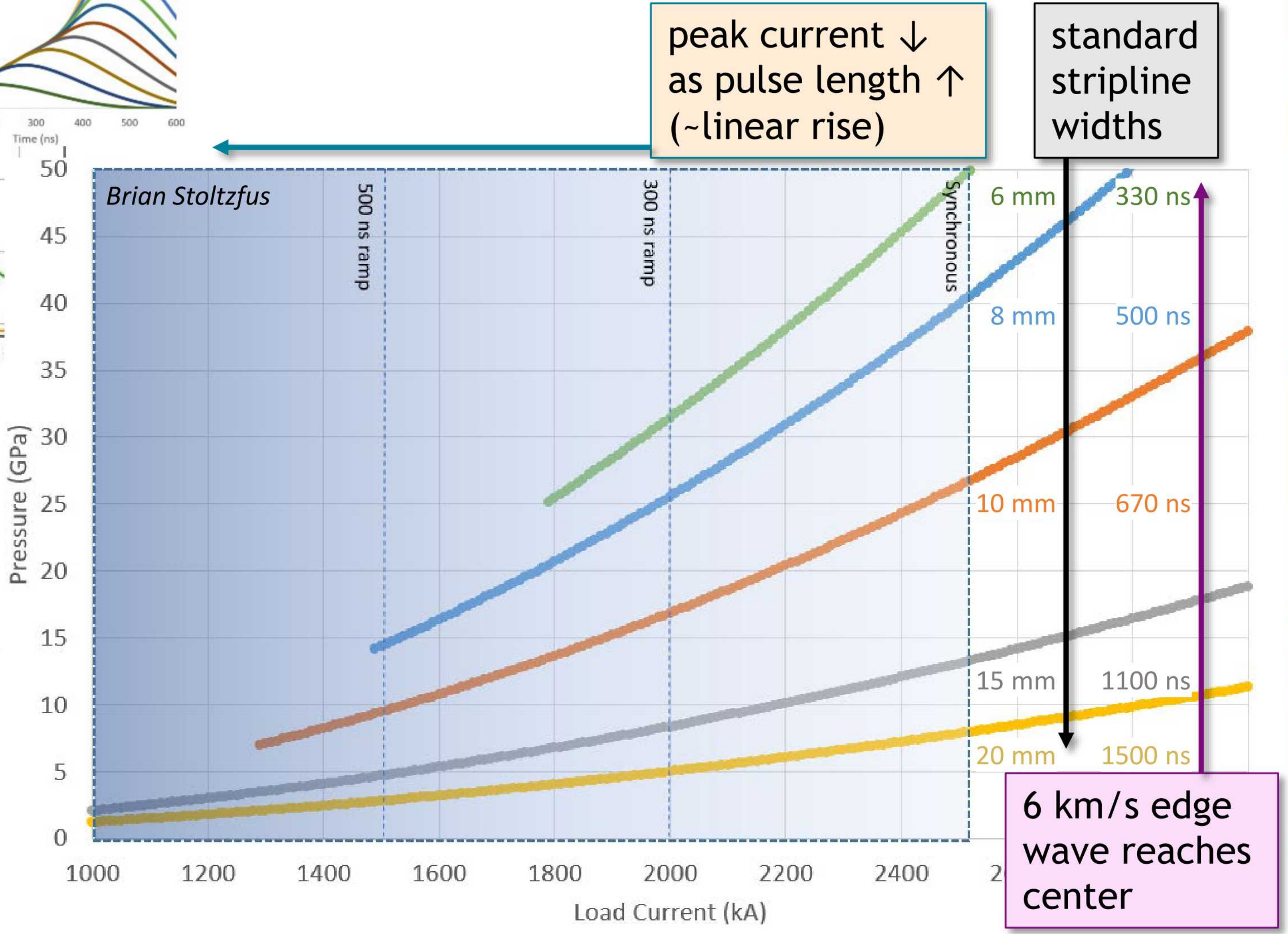


Thor experiment design requires trade-offs among sample size (panel width), pulse rise time, peak pressure, and edge waves





Pulse shape is simple superposition of basis functions (when dynamic inductance can be neglected)



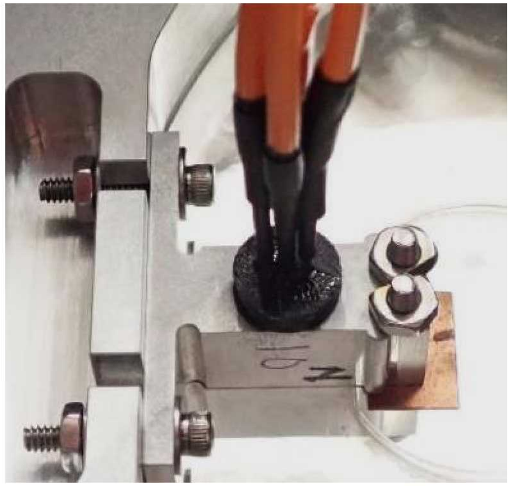
1. Choose a peak pressure
   - Restricts choice of panel width
2. Decide on desired pulse shape (loading rate)
   - Restricts peak pressure for given width
3. Determine required measurement time window
   - May further restrict width, pressure, loading rate
4. Iterate using 1-D numerical simulations
   - 2-D simulation if dynamic inductance is large (narrowest panels at highest currents)

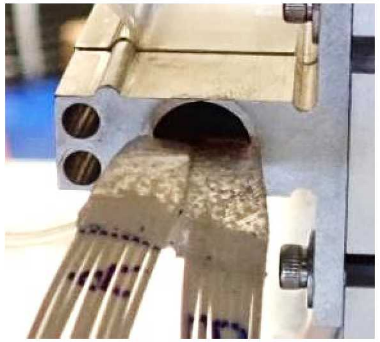
Primary diagnostic used at Thor is laser-based velocimetry

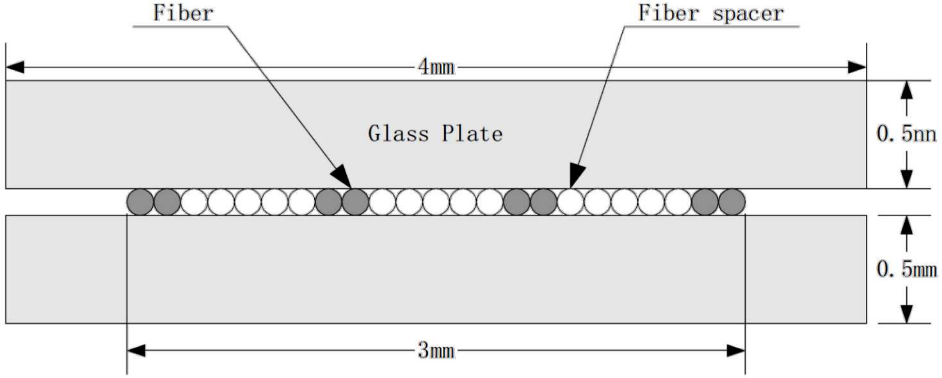
Air-delay VISAR system
- Up to 9 channels, automatically dual sensitivity
- VPF as low as 12 m/s/fringe

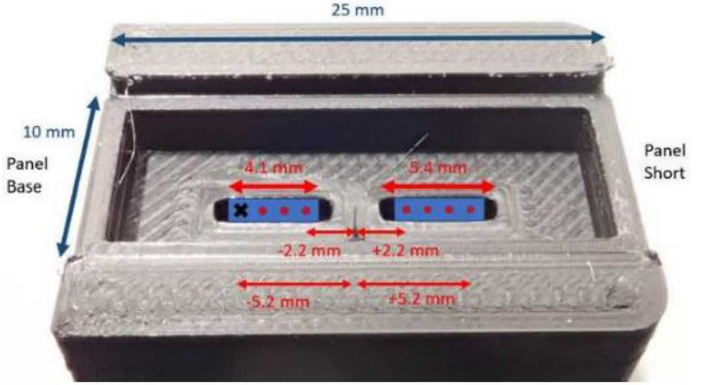
PDV system
- Up to 8 channels, with arbitrary frequency shifts
- Collimated, focusing, or bare two-fiber probes
- Array probes (uniformity, statistics)
- Frequency multi-plexing (intra-array cross-talk)

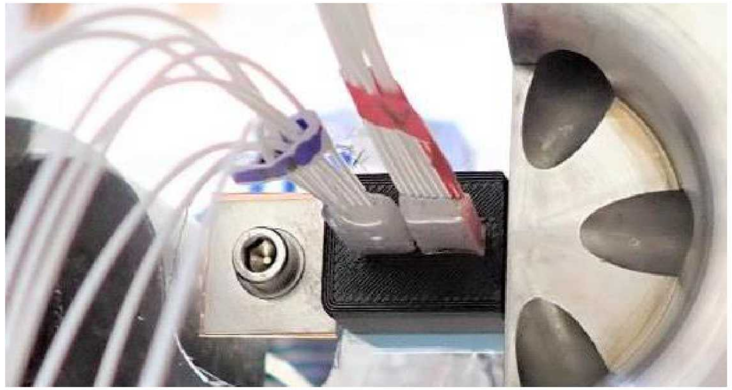
Custom 3D-printed probe holders



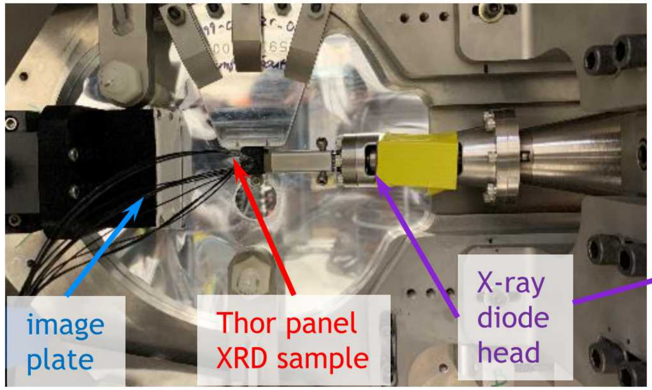




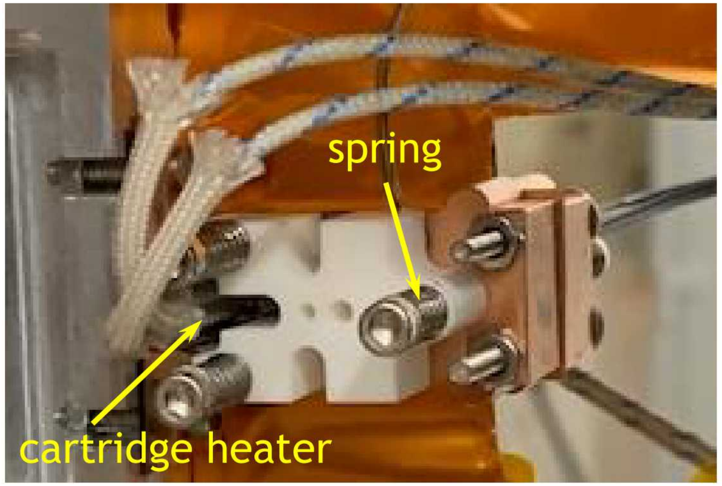




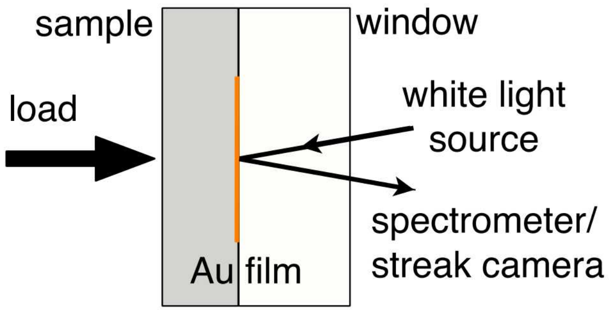
Thor is ideal to test and develop other diagnostics/subsystems



X-ray diffraction (XRD)
- 1.1-MV needle-and-washer e-beam diode system
- 30-ns pulse of line and bremsstrahlung emission
- 8.0 keV (Cu), 17.4 keV (Mo), 22.1 keV (Ag)
- Conical head with 90° turn
- Reflection geometry, 9-25° incidence angle
- Angular resolution ~0.7° FWHM, ~0.2° shifts
- Issues raised by 2019 tests have been solved



Resistive pre-heating
- 50-W cartridge heater in base side of each panel
- PIV feedback control of panel temperature near sample
- Spring-loaded ceramic probe holder sample/window
- Demonstrated to 380°C (Kapton insulator limit is 400°C)



Optical spectroscopy
- Streaked visible spectroscopy (real-time reflectance)
- Thermo-reflectance methods under development
- Mid-infrared band pyrometry under development (T > 325°C)

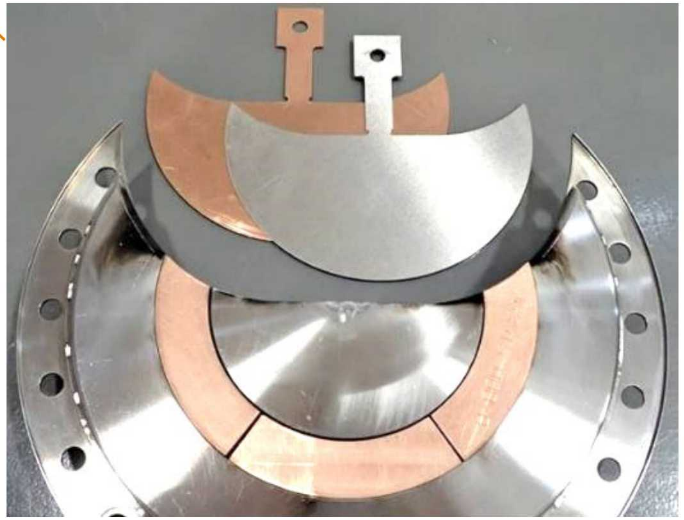
Possible to field vacuum chamber around target

Thor is part of the Dynamic Integrated Compression Experimental (DICE) facility at Sandia

DICE building is outside restricted area, allowing uncleared and foreign-national visitors

On-site target characterization and assembly capabilities include:

- Class 100 clean room
- Precision (optical) metrology, sample preparation
- Measure mass, density, ultrasonic longitudinal/shear sound speeds
- Rapid prototyping (3-D printing)
- Limited machining, but includes water-jet cutting of "sheet" panel targets



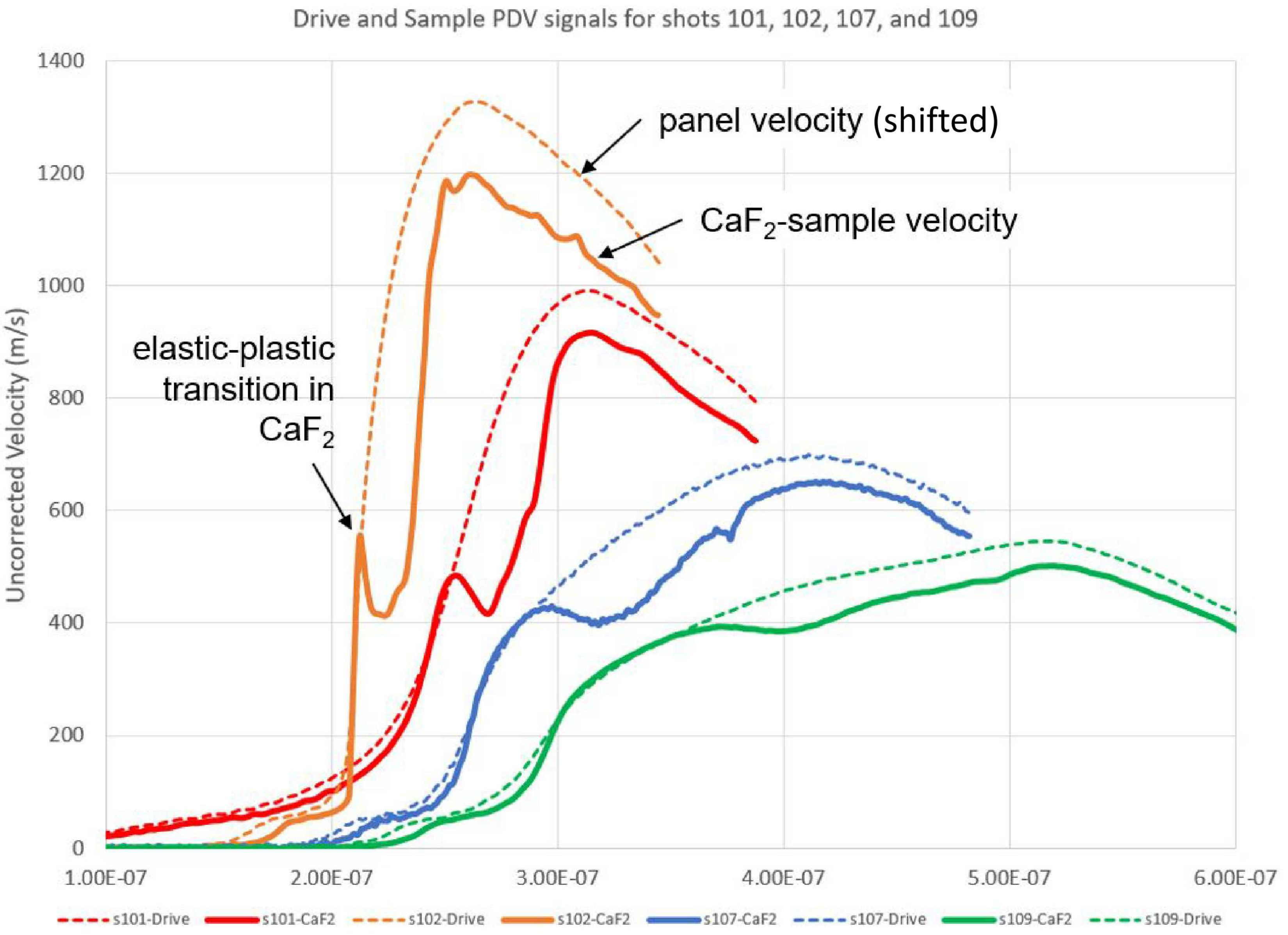
Additional dynamic-compression drivers

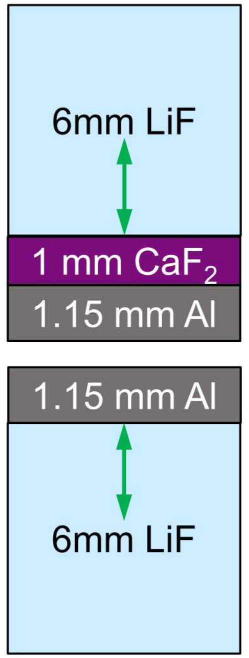
- Veloce small pulser
- 3"-bore single-stage gas gun

Briefly present ten examples of recent work performed at Thor

- **time-dependent constitutive response of CaF_2** (Seth Root, Patricia Kalita)
- **strength of phase-transforming Sn** (Justin Brown)
- **strength of additively-manufactured stainless steel 304** (Paul Specht)
- **Rayleigh-Taylor instability growth in PMMA** (Justin Brown, Paul Specht)
- **ramp compression of single-crystal Sn** (Justin Brown, Jason Scharff)
- **kinetics of dynamic solidification in liquid Ga** (Justin Brown, Jon Belof)
- **X-ray diffraction measurements on Zr, Al** (Tom Ao, Dane Morgan)
- **refining electrical conductivity model for Cu** (Andy Porwitzky, Kyle Cochrane)
- **quantifying uniformity of loading in Thor striplines** (Jean-Paul Davis)
- **densification of hydrous silicate glasses** (Jean-Paul Davis, Alisha Clark)

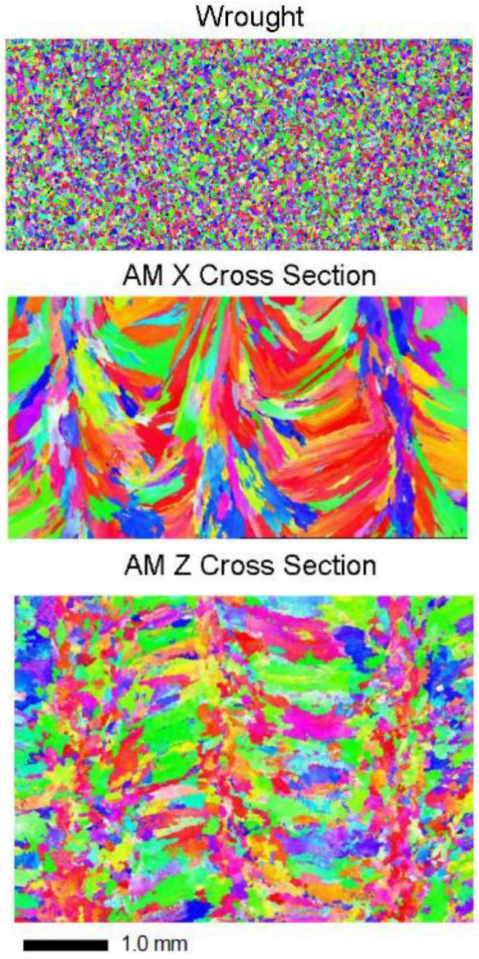
Single-crystal CaF_2 (S. Root, P. Kalita)





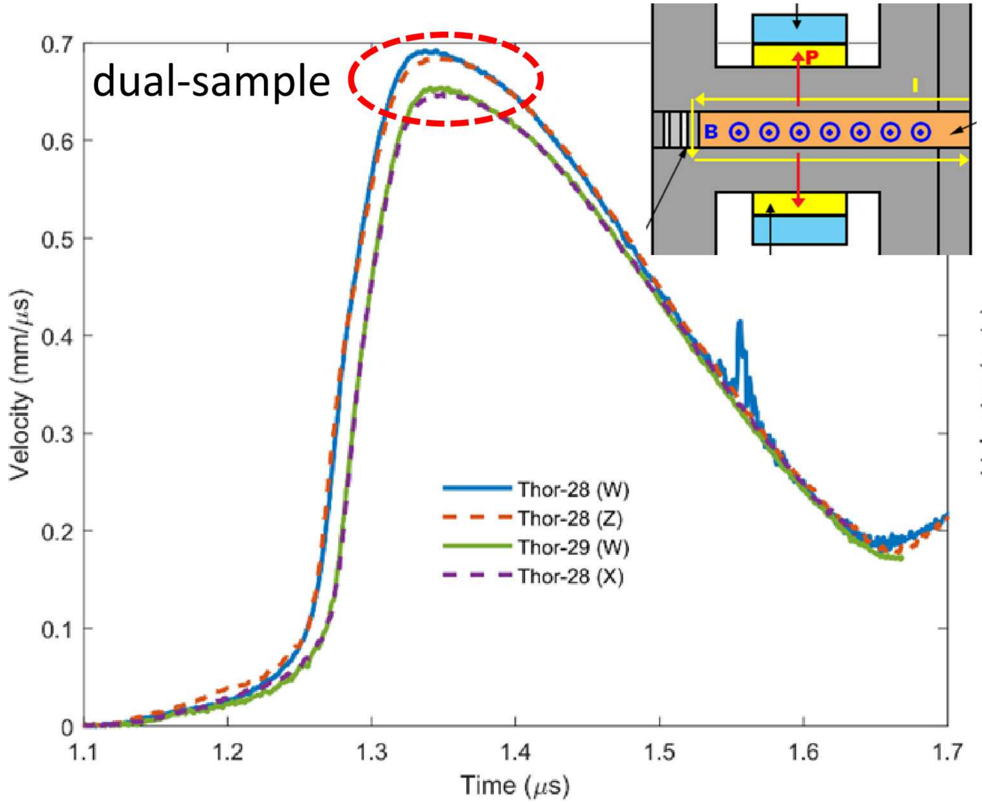
- Loading rate was varied by ~40X, resulting in dramatically different signatures of the elastic-plastic transition.
- Data can be used to constrain the time-dependent nature of the constitutive response.

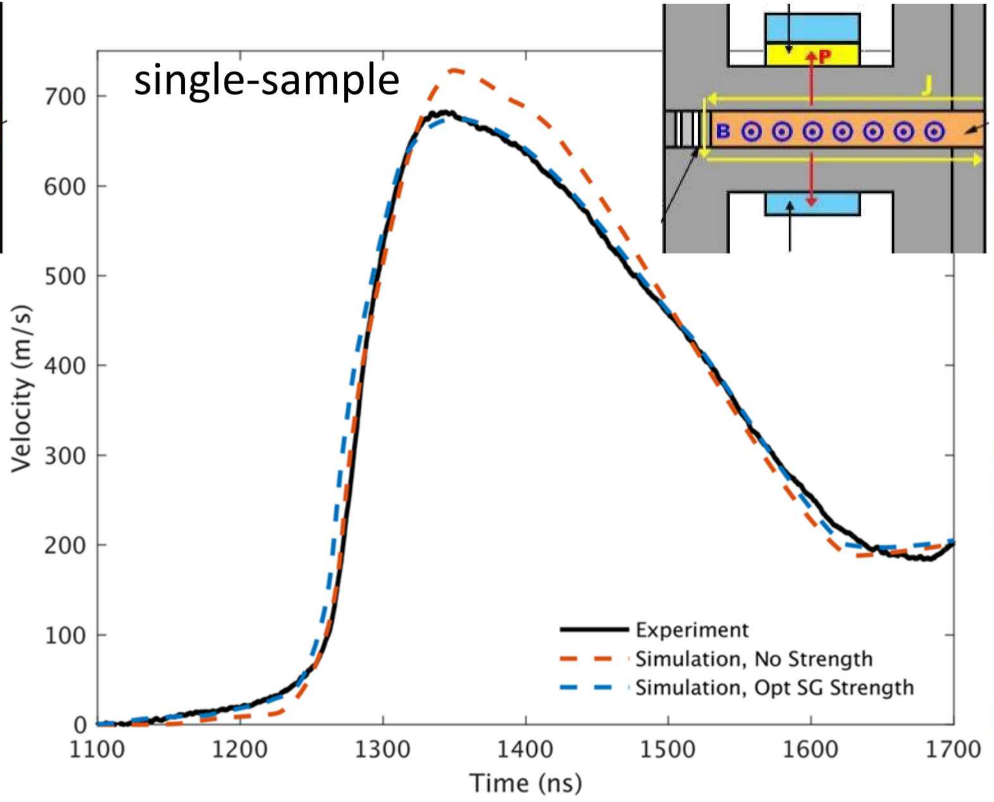
Strength of AM LENS™ 304L Stainless Steel (P. Specht)



LENS = laser-engineered net shaping

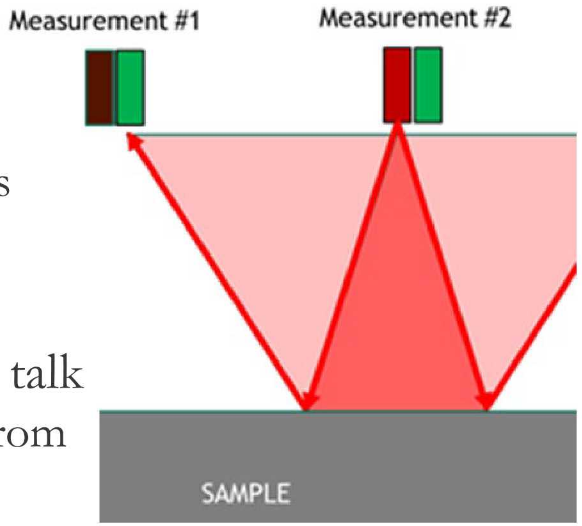
- Flow strength generates differences near peak stress
  - Lower velocities correspond to higher yield strengths
  - Dual-sample: both AM orientations exhibit higher flow strength than wrought
  - Single-sample: strengths similar but wrought may be higher
- Results suggest possible issues with experimental dimensions generating large sample-to-sample variations

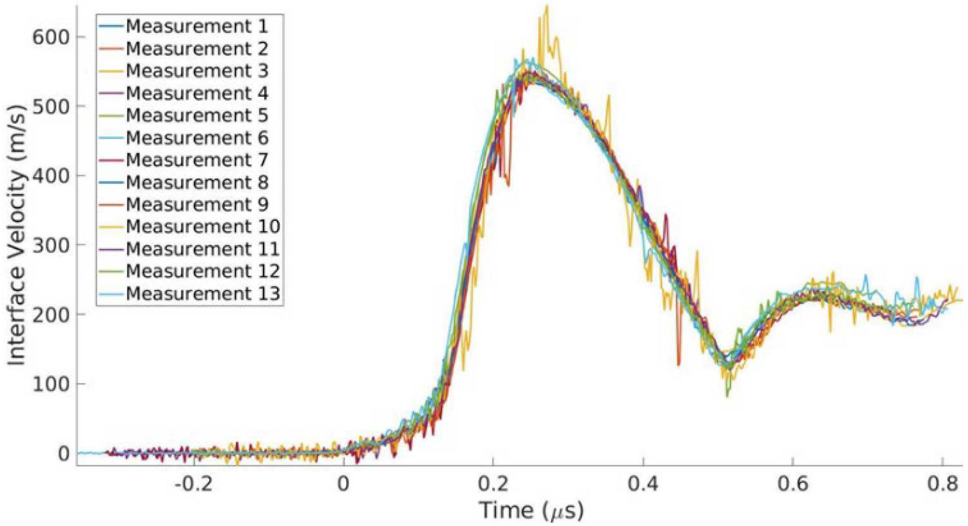


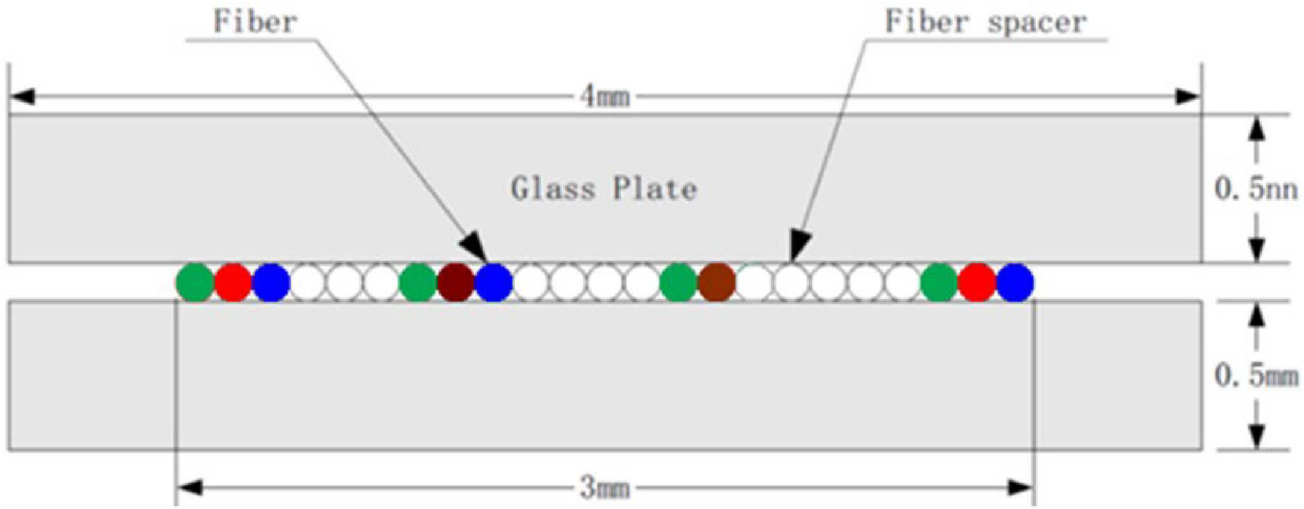


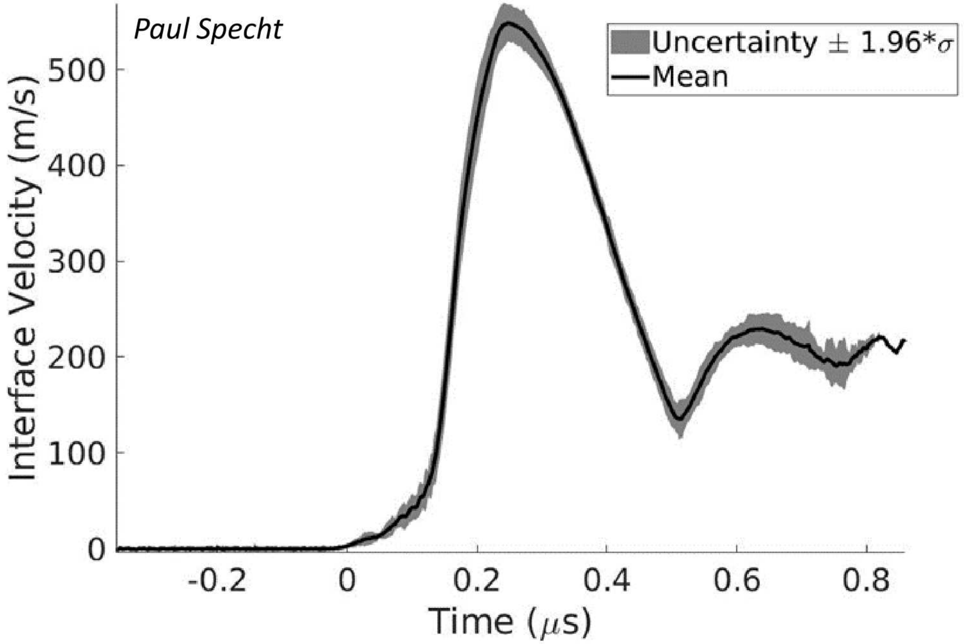
Multi-point velocimetry can address statistical material response

- Use a commercially available fiber array
  - 3 different frequency high-power send lasers
  - 2 different frequency reference lasers
- The low velocities allow frequency multiplexing of all signals including cross talk
  - Obtain measurements at one receive fiber from 2-3 send fibers

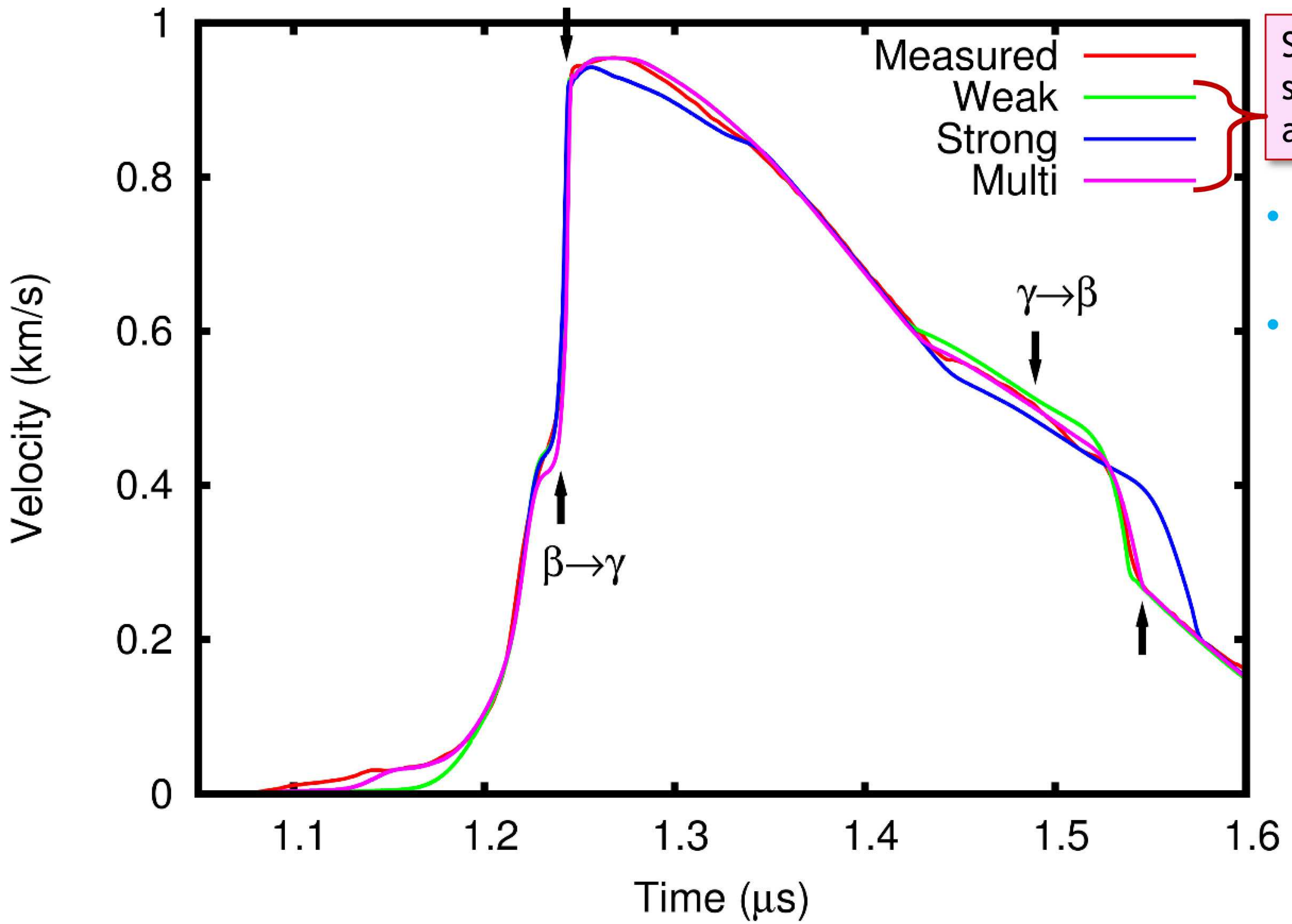






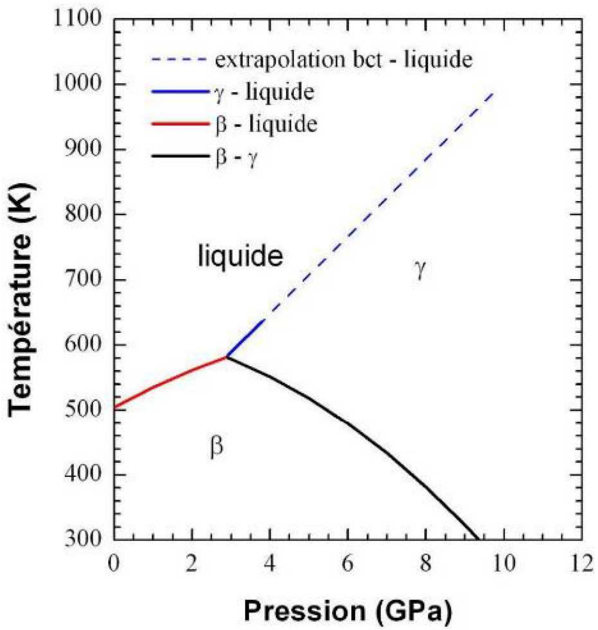


Multi-phase strength of Sn (J. Brown, J. Carpenter)



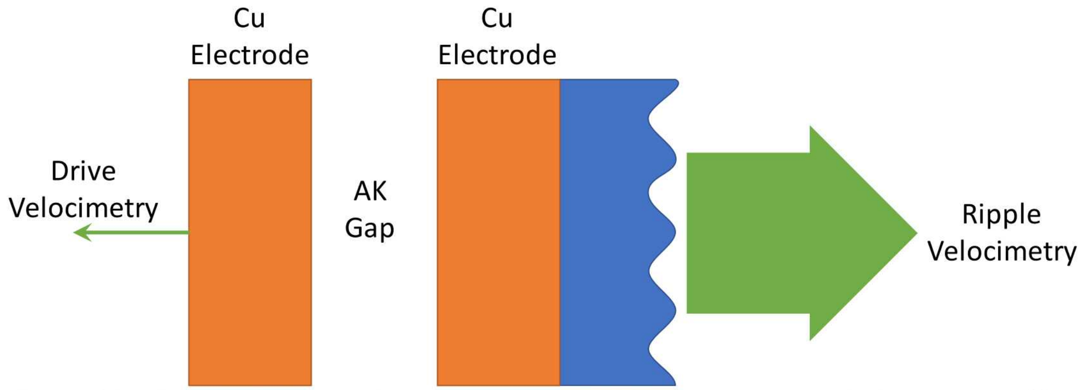
Simulations using different strength models, including a multi-phase model

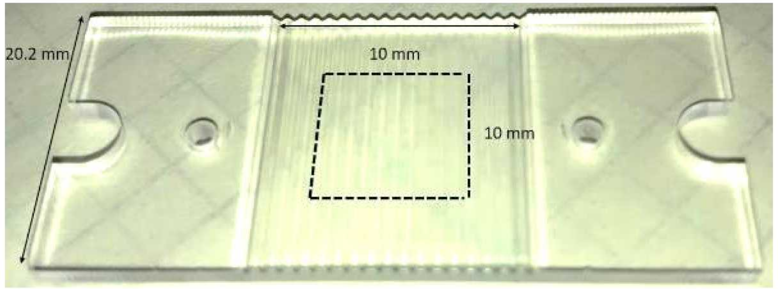
- Measured velocity is a combination of EOS, phase transition kinetics, and strength.
- With different loading rates on Thor we may be able to uniquely identify these different aspects

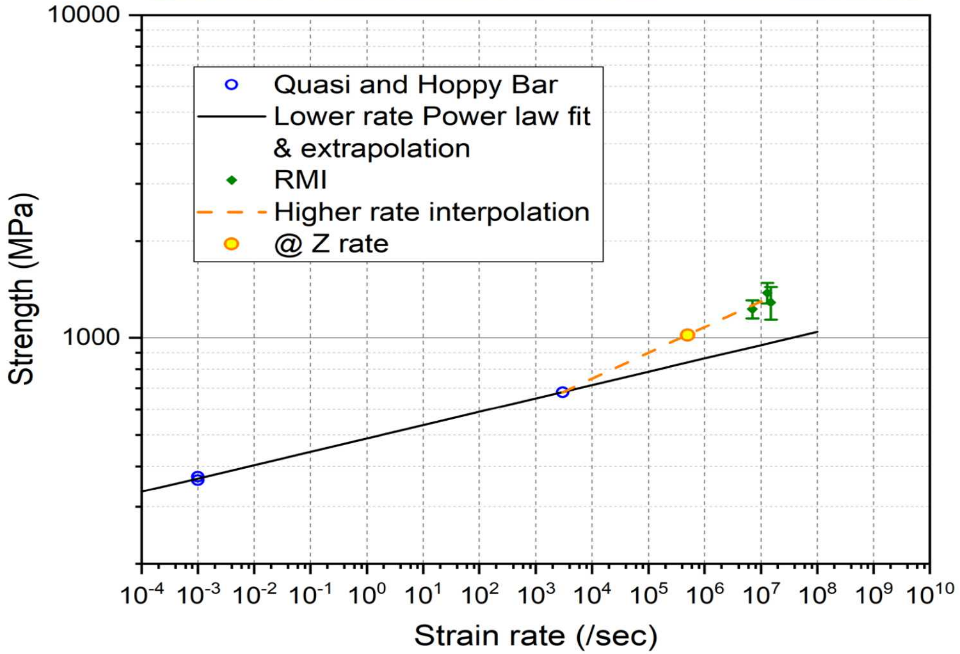


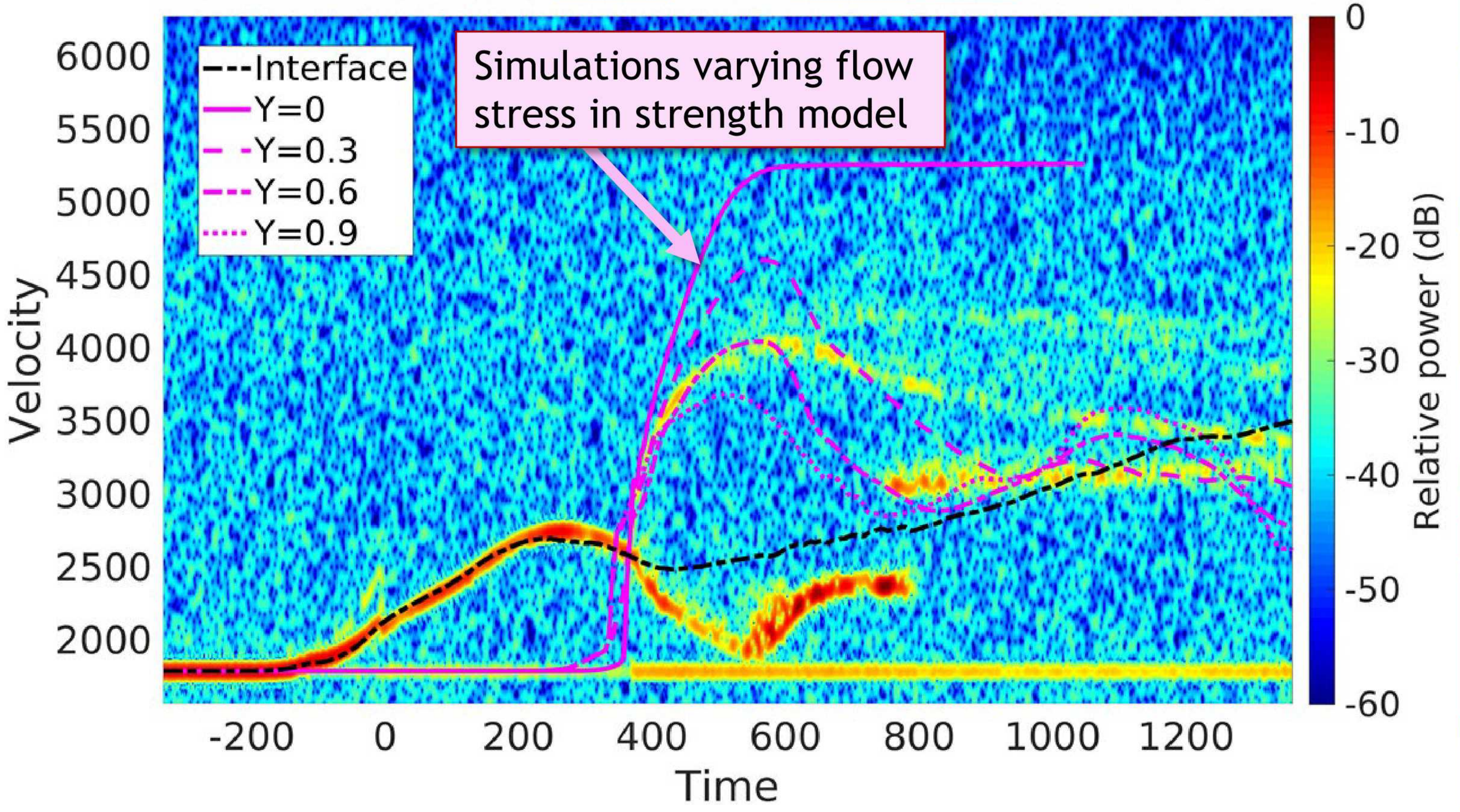
Rayleigh-Taylor instability growth of PMMA (J. Brown, P. Specht)

- Easy to machine ripples in PMMA
- PDV simultaneously probes front and back of PMMA
- Filling a critical gap between Hopkinson bar and shock-driven Richtmyer-Meshkov experiments.



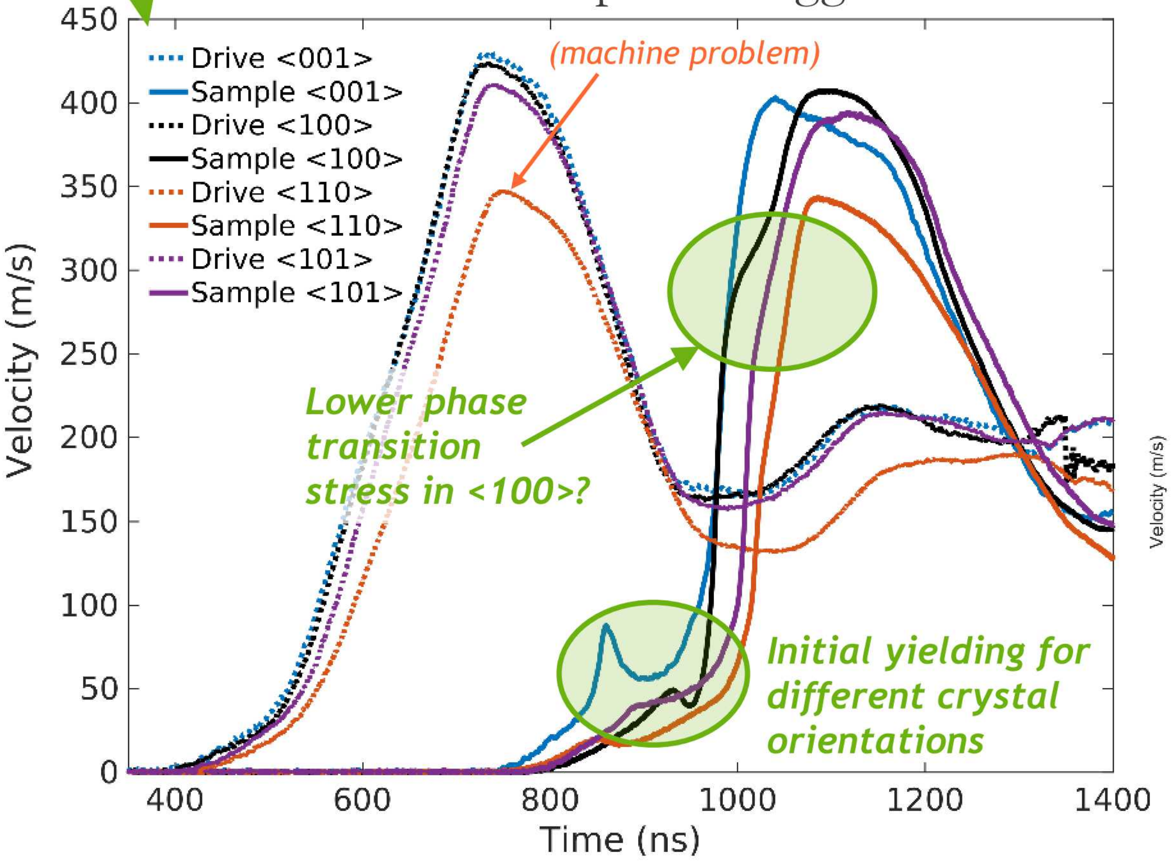


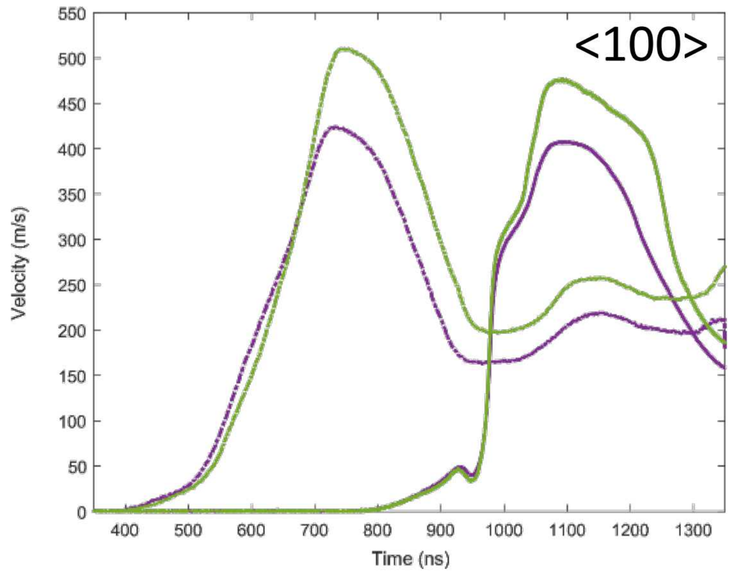


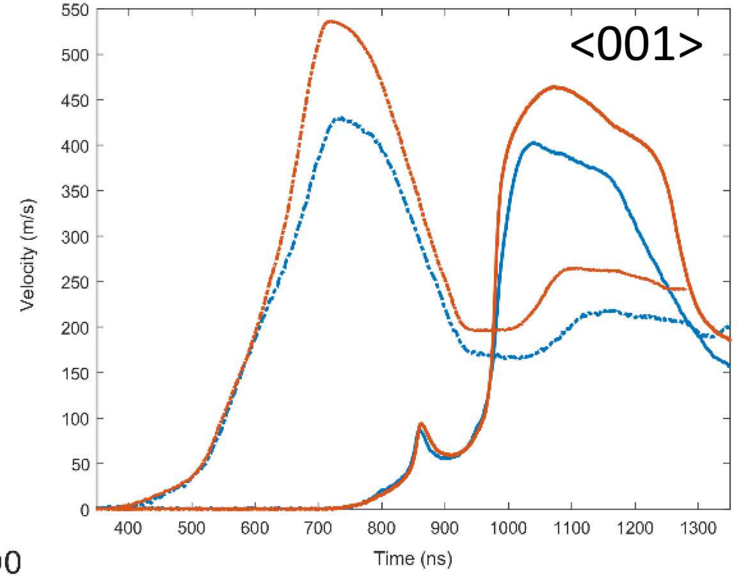


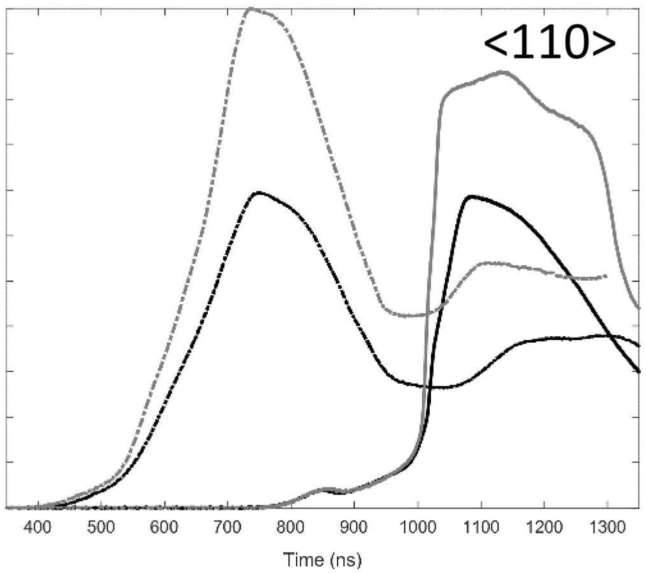
Tin single crystals (J. Brown, J. Scharff)

- Four crystal orientations, identical machine configurations
  - Material response for each orientation is very different from others
- Repeat the loading rate but go to higher pressures
  - Observed elastic-plastic transition is highly repeatable
- Nothing distinct at higher pressures in <001> and <110> but the behavior near peak is suggestive of something odd happening

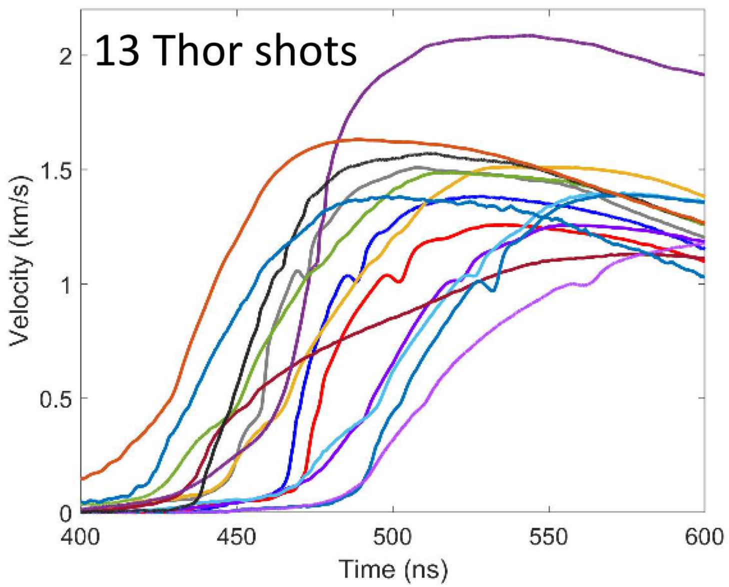






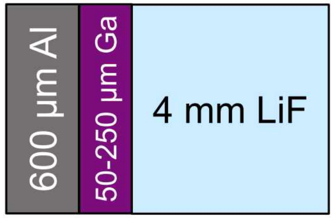


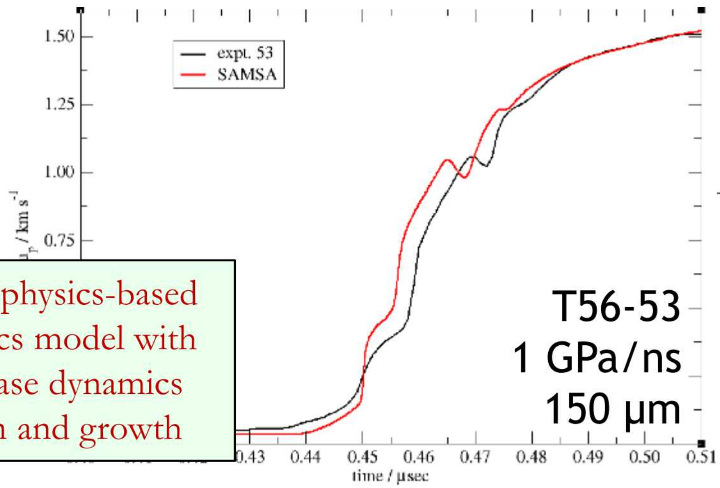
Kinetics of dynamic solidification in Ga (J. Brown, J. Belof)

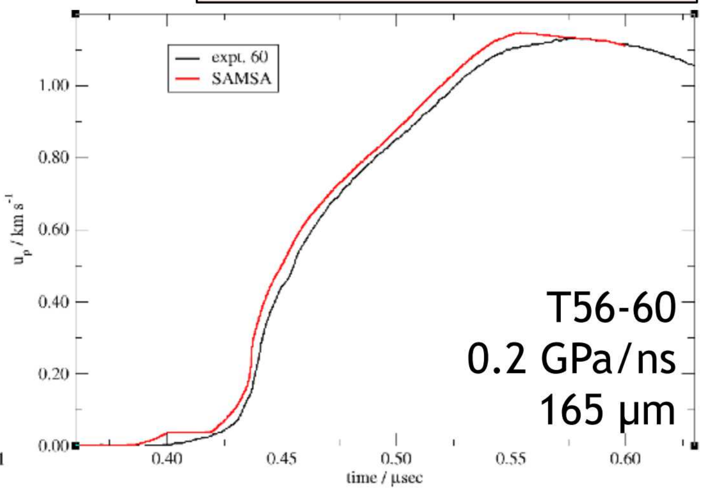


- Al panels (heated to ~34°C) and LiF windows
  - type-IIB anodized Al to avoid embrittlement by liquid Ga
  - LiF acoustic impedance similar to ℓ-Ga, uniform sample loading
- Vary pulse shape (loading rate) and sample thickness

Model predicts solidification complete in **all** experiments, but pullback signature only visible when loading fast enough or sample thick enough

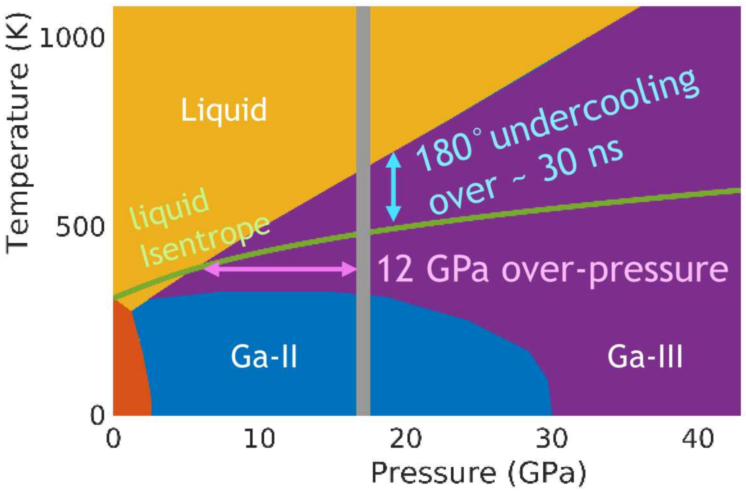






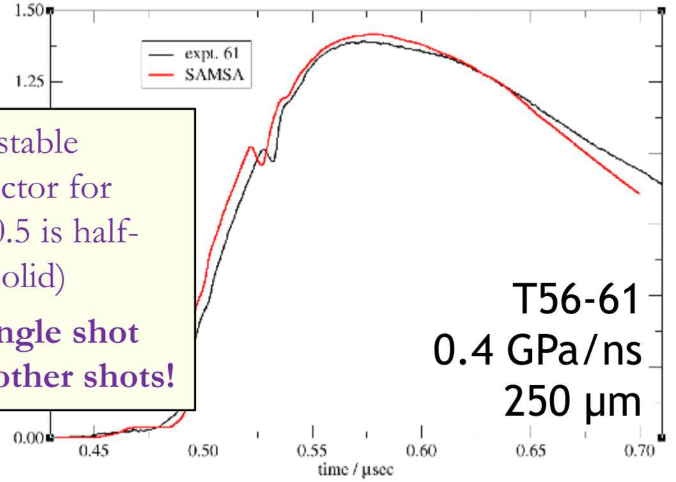
SAMSA = LLNL's physics-based solidification kinetics model with time-dependent phase dynamics based on nucleation and growth

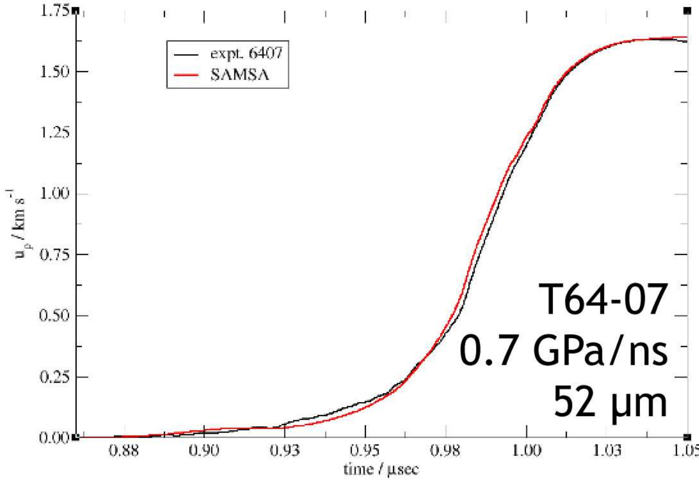
Fast solidification occurs at metastability limit due to homogeneous nucleation



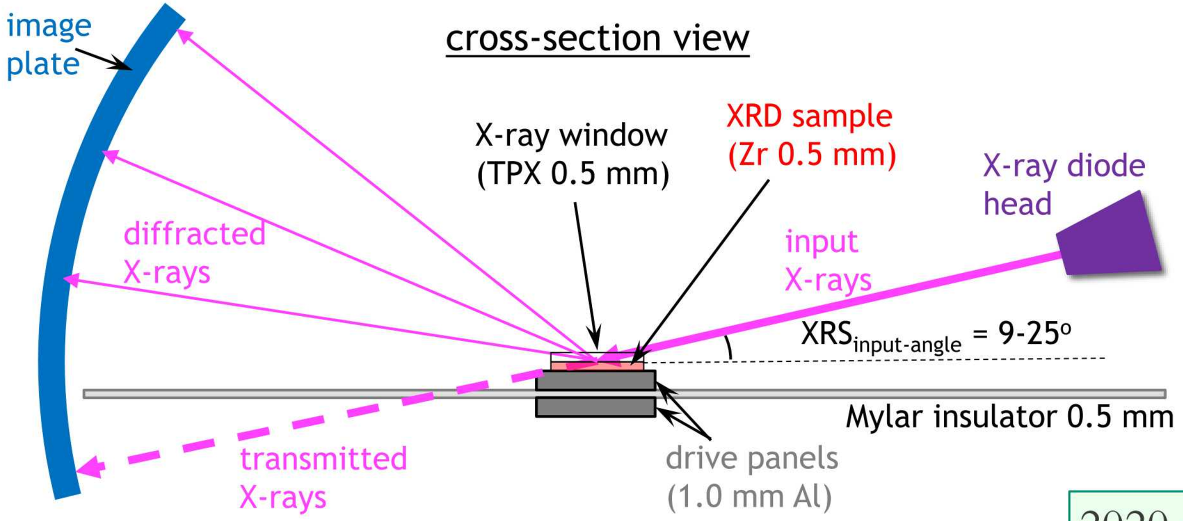
Model has only one adjustable parameter ξ = volume factor for liquid adjacent to solid (0.5 is half-way between liquid and solid)

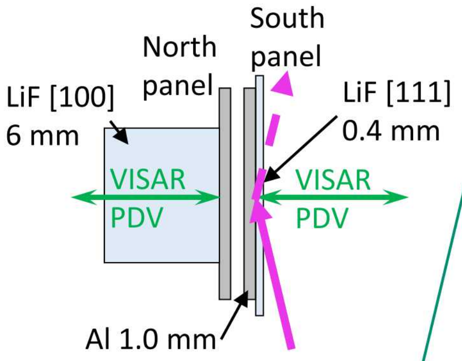
ξ = 0.44 by fitting to single shot T56-53 reproduces all other shots!

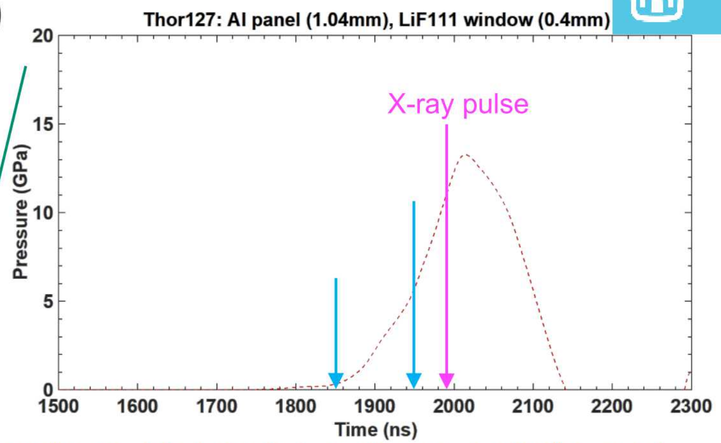


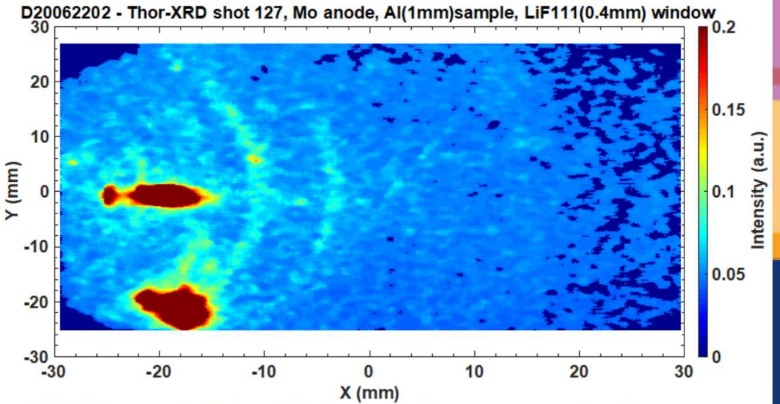


X-ray diffraction measurements (T. Ao, D. Morgan)



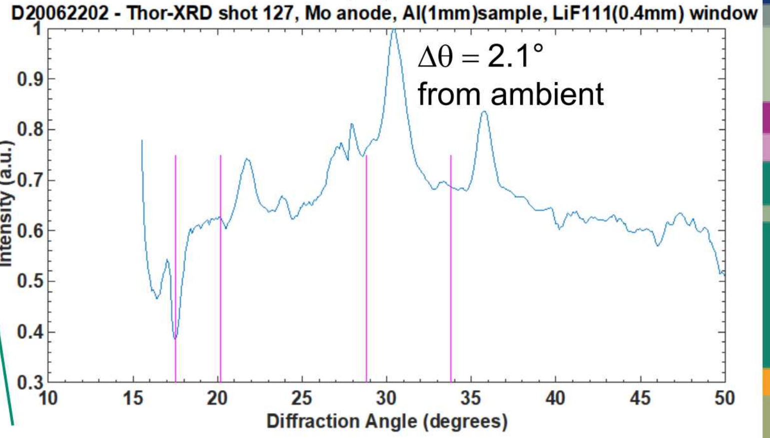


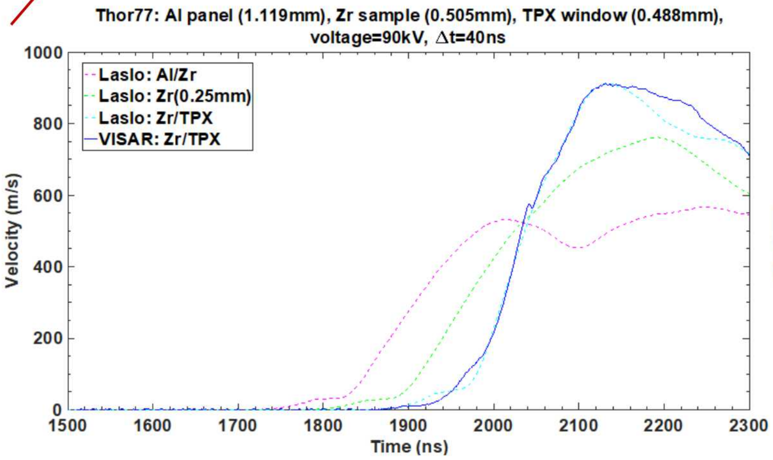


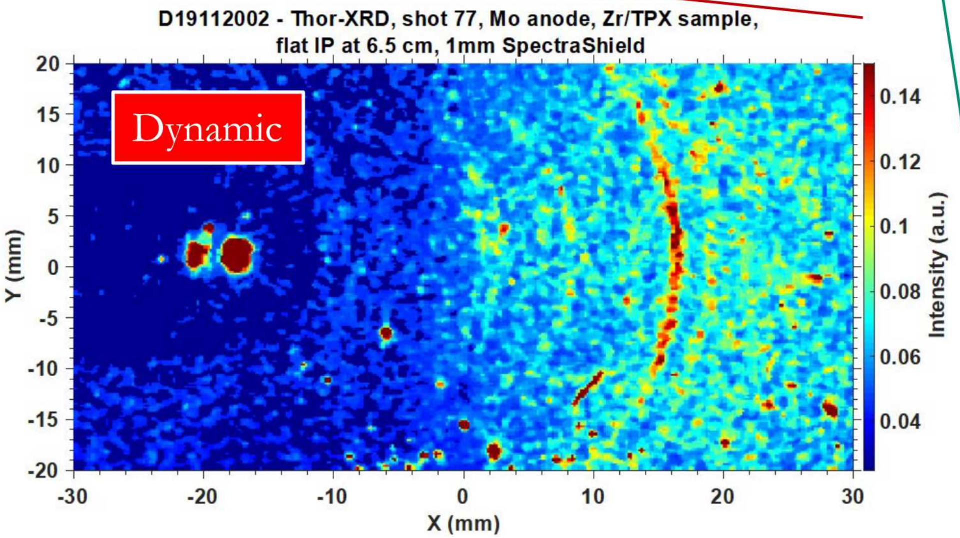


Early 2019 experiments on Zr, CdS:
- Thor / flash-diode timing issues
- every shot damaging CPF Rexolite insulator

2020 experiments on Al:
- problems have all been addressed
- multiple shots, vary X-ray timing

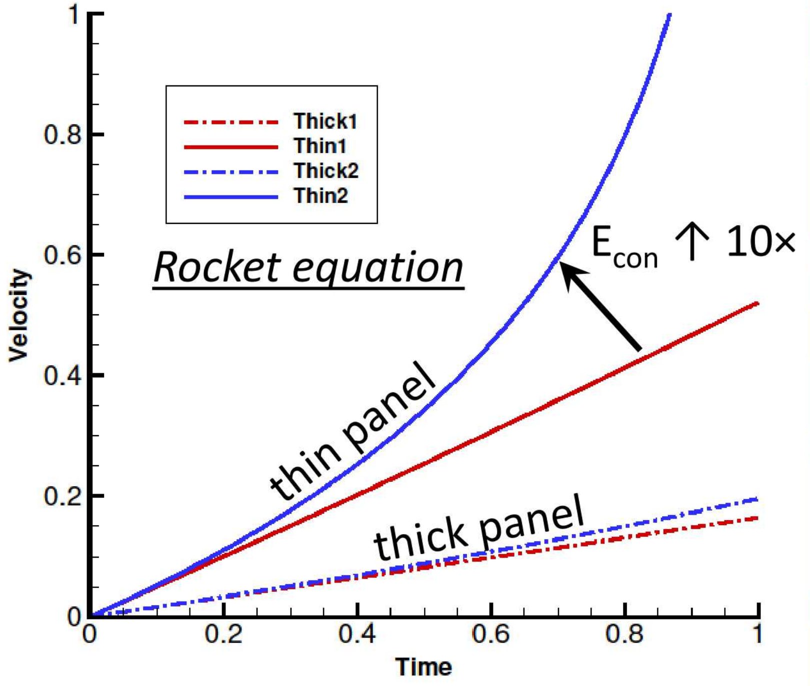


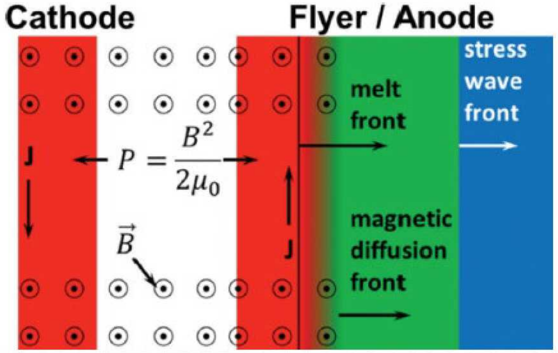


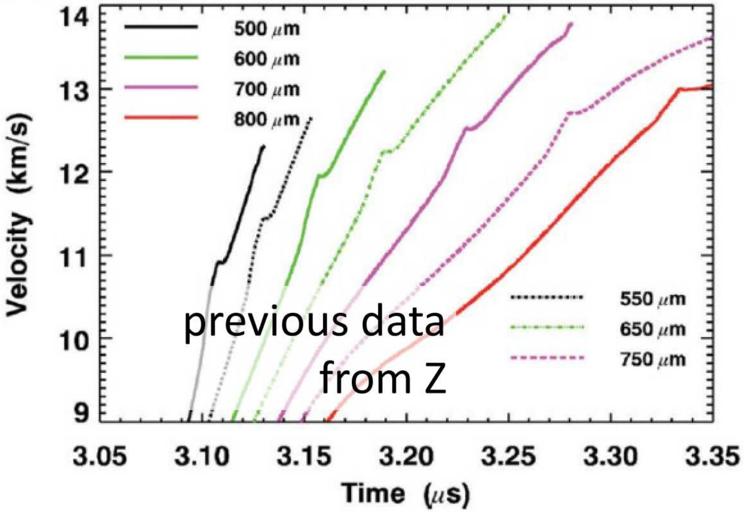


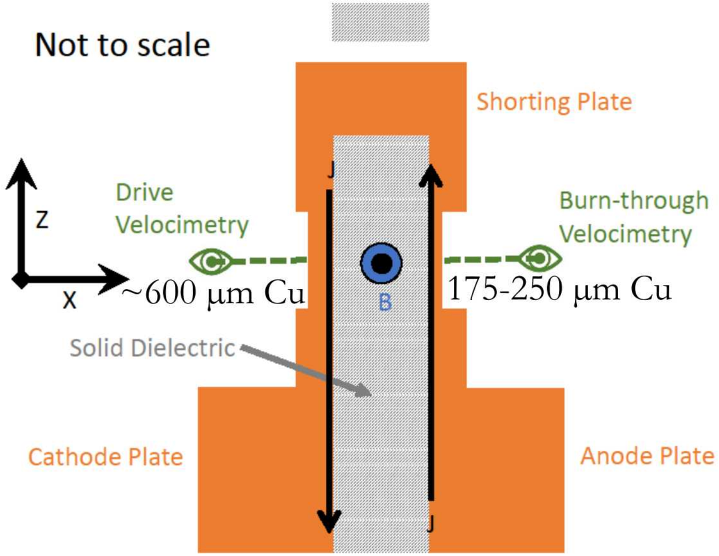
Electrical conductivity of Cu (A. Porwitzky, K. Cochrane)

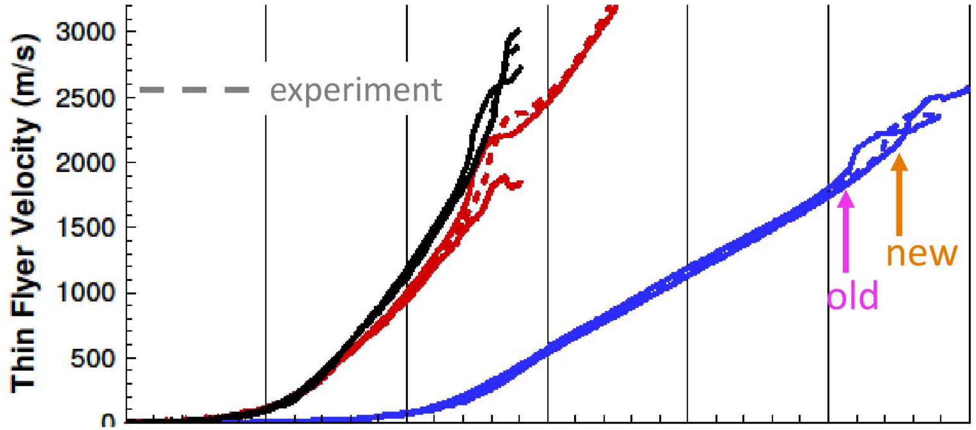
- Conductivity E_{con} calibrated to "burn-through" of thin electrodes
  - match time of velocity uptick when melt front reaches free surface
- Velocity of thick electrode on opposite panel **not** sensitive to E_{con}
  - given B-field diffusion rate, fractional mass loss much less for thick panel
- Unfold thick-panel drive, optimize tabular E_{con} modifications to match thin panel burn-through
  - E_{con} for Cu previously tuned to Z data
  - had to significantly increase E_{con} along isotherms in temperature range ~2000-7000 K near melt curve
  - Thor far more sensitive to this region than Z







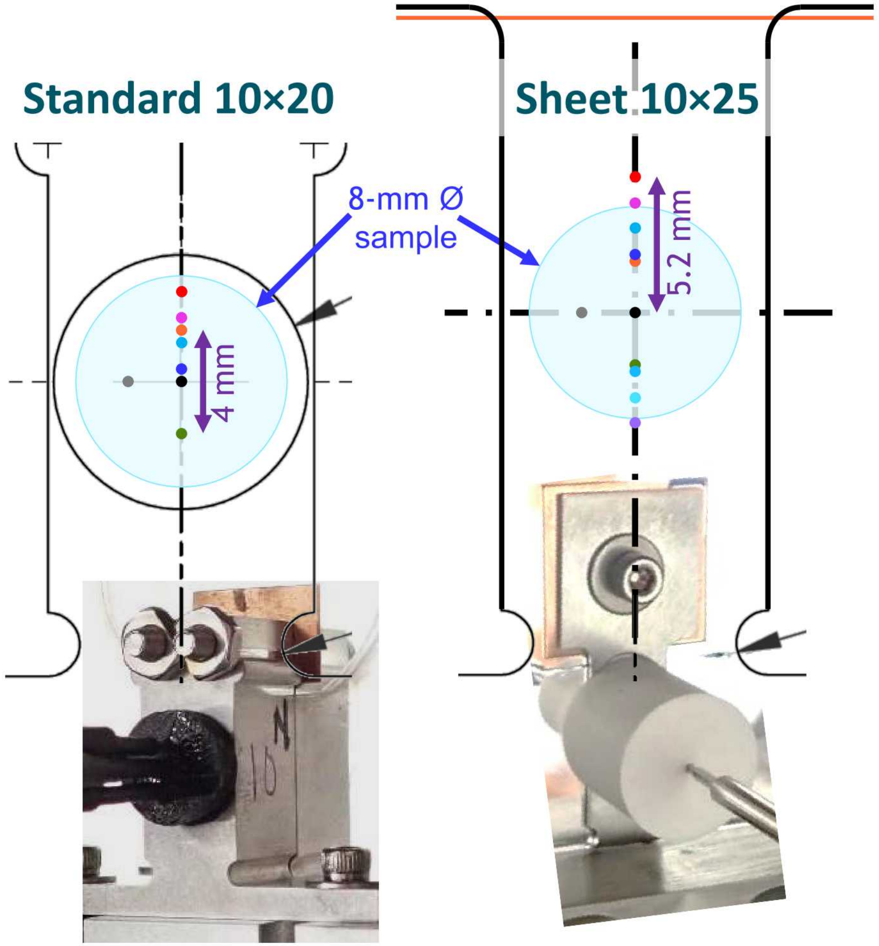




Uniformity of magnetic-pressure loading (J.-P. Davis)

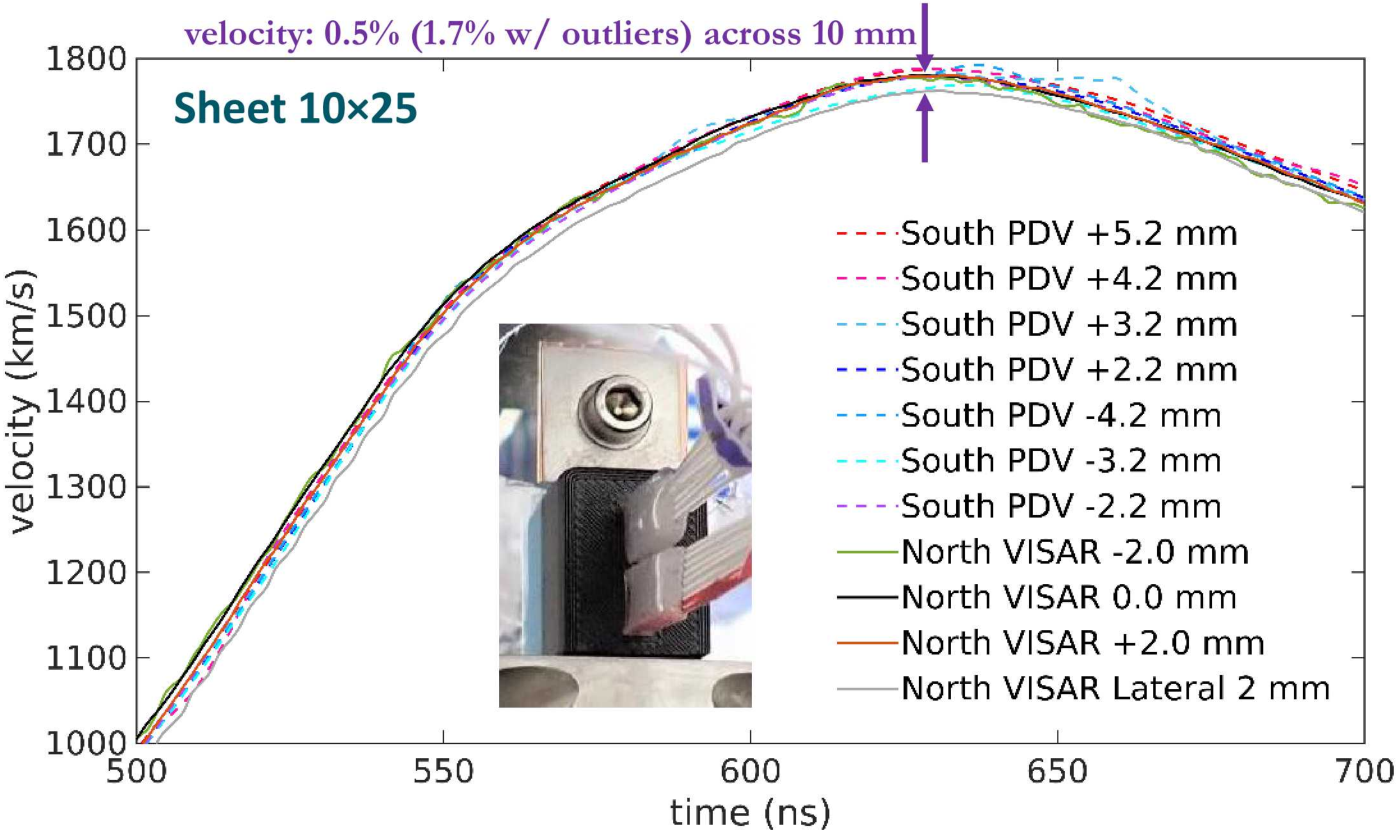
Standard Thor panel sizes keep 2:1 (length:width) aspect ratio of original Veloce stripline

- 15×30-mm Veloce stripline exhibits ~2% variation in magnetic pressure across 12-mm sample
- not clear whether gradient scales self-similarly to smaller sizes
- measured ~2% variation across only 4 mm in 10×20-mm Thor panel (1-mm floor in 0.5” thick panel)



Tested water-jet cut 1-mm thick “sheet” panel (10×25 mm)

- < 1% variation across ~10 mm along centerline



Densification of hydrous silicate glasses (J.-P. Davis, A. Clark)

- Supports the "Origin of Earth's Water" Z Fundamental Science project
- Elastic properties of hydrous/anhydrous silicate glasses under ramp compression are relevant to interpretation of mantel-transition-zone (MTZ) seismic data
- "Densification" of glasses = anomalous compressibility, sound speed depends weakly on pressure
- Data collected on dry/damp (100/400 ppm H_2O) magnesium silicate glasses for range of pressures, pulse shapes
- Preliminary results suggest densification begins above 10 GPa, not complete by 18 GPa